Influence of the Substrate tube Quality on TSL Features of Yb-doped Silica Preforms of Optical Fibres

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ABSTRACT

We have demonstrated by spectral analysis of thermally stimulated luminescence that depending on the quality of the substrate-tube used during the MCVD technique, Yb-doping of silica preforms might be responsible for both the formation of the non-bridging hole centres (NBOHC) and their amount within the final preform. If these centres as well as those originating from the substrate tube are still present even after drawing, they will give rise to absorbing defects and thus a detrimental effect – like photo-darkening - on the performance of the ytterbium-doped optical fibres serving as amplifier (YDFA) or in high-power fibre lasers.

To describe the TSL of Yb-doped preforms, we also propose a mechanism based on the oxidation/reduction process involving hole traps and Yb impurities as recombining centres.

PACS Keywords: Thermoluminescence, silica, point defects, radiation, ytterbium.

1 INTRODUCTION

Among possible applications of active fibres, Yb-doped silica fibres are well appropriate for high-power fibre lasers and amplifiers (YDFA). Nevertheless, such fibres exhibit severe transmission losses in visible with a tail reaching the spectral region around 1 μm where Yb-doped fibre lasers and amplifiers operate. These optical losses during operation of YDFA, known as photodarkening, as well as some possible physical mechanisms responsible of this effect have also been reported [1,2].

In this work, we introduce an original approach based on the thermally stimulated luminescence (TSL) and its spectral analysis. This technique offers the advantage of reflecting both recombination centres (e.g. Yb) and defects that absorb in a wide wavelength range (from UV up to NIR), thus participating probably in photodarkening. In addition to the characteristic emission of Yb, our measurements also reveal the luminescence pattern of NBOHC and that of other centres already present within the substrate tubes used for the MCVD.

2 MATERIALS AND EXPERIMENTAL DETAILS

The samples presented here consist of two pieces named TA and TB cut from two different commercially available fused-quartz substrate tubes and two round polished slices (1 mm thick) cut from the preformed rod grown by MCVD. The preforms PA and PB, made with tubes TA and TB respectively are of the same compositions: impurities are introduced by doping solution technique. TSL measurements were performed using a homemade reader. After irradiation by X-rays (45 kV, 30 mA) at room temperature (RT), TSL readout was performed by linear heating rate of 1 Ks^{-1} from RT to 773 K. The signal was recorded by means of a PM tube and an optical multi-channel analyser equipped with a CCD matrix detected the spectral distribution of TSL peaks.

3 RESULTS

TSL curves relative to preform PA and substrate tube TA are characterised by the same peaks with intensities of same order of magnitude and are composed of one main peak at 433 K and a small one at around 730 K. The similarity in peak positions indicates that at least two similar defect groups are populated by irradiation in both samples. These broad peaks are the result of the thermal release from closely distributed trap levels spread within the band gap.

TSL curves relative to preform PB and the corresponding tube TB do not show the TSL peak observed around 730 K in PA and TA. One assumes that it exists but because of its low intensity, it cannot be detected and probably hidden within the blackbody radiation. For the same conditions of irradiation and readout, the TSL curve of preform PB is characterised by two peaks located near 390 and 503 K. These two peaks probably exist in the glow curve of PA preform but hidden within the main broad peak at 433 K dominating the TSL signal. Indeed, the maximum TSL intensity of PB is much lower than that of PA. Concerning the substrate tube TB; it is not thermoluminescent at all. In terms of point defects, it means that the substrate tube TB is of much higher quality, compared to the tube TA.

According to TSL glow curves, one may consider that in addition to trap defects probably formed during synthesis of the PB preform and made from highest quality substrate tube, some other defects originating from the substrate tube TA itself still prevail during collapse of the preform PA.
Afterwards, in order to know more about the defects acting as recombining centres in the TSL process of the substrate tube TA, spectral analysis of the emission of its 433 K peak is carried out. It shows three bands peaking at around 1.56, 2.4 and ~3.1 eV. The 3.1 eV band might be related to $B_{2\beta}$ centre already observed in PL in fused silica glass after both γ and X irradiations [3]. The two other components are not relative to any well-known defect reported yet in silica.

Spectral distribution of the main peaks observed at 433 and 503 K on respectively PA and PB glow curves is presented on Fig. 1. For both preforms, the predominant feature in the spectra is the main characteristic emission of the $^2F_{5/2} \rightarrow {}^2F_{7/2}$ transition of Yb^{3+}ions that seems to be unique in the spectrum of PB. Thus one can consider that the only recombining centres occurring in preform PB are Yb ions whereas in the case of preform PA, besides the dominant Yb^{3+} emission, one can see that the emissions at 1.56 and 3.1 eV, already observed in the corresponding substrate tube TA still occur while the 2.4 eV band is completely quenched. The defect relative to this last band has been probably annealed during the preform synthesis. The new feature is the appearance on the spectrum of a pronounced shoulder at around 650 nm (1.9 eV).

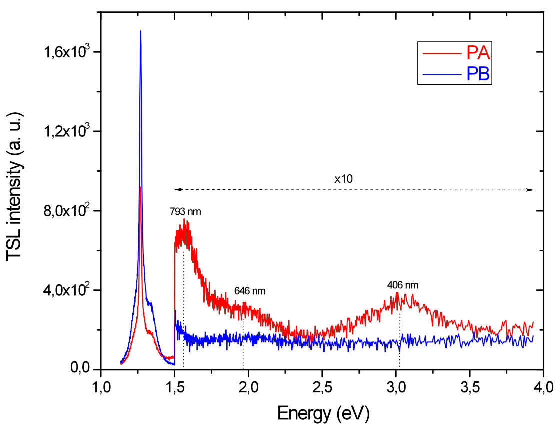

Fig. 1. Emission spectra of 433 and 503 K TSL peaks obtained on PA and PB preforms respectively

4 DISCUSSION

It is shown in this study that at least two main trap defects are involved in TSL of each preform. The main emission of these TSL peaks is that of Yb^{3+}ions at 1,27 eV. Hence, even if the origin of the trap defects still remains unknown, one can advance the hypothesis that these traps are of the same nature since they give arise mainly to the same luminescence emission. Thus, one probable physical mechanism describing the observed TSL signal in these Yb-doped preforms might be the classical redox process.

According to this possible mechanism one can refine our previous hypothesis regarding the origin of traps by considering that all the TSL peaks observed on both preform correspond to hole trap defects.

Besides the trivalent Yb emission, the spectral emissions shown on Figure 1 have a shoulder at around 1.9 eV (PA) and a very weak signal at the same energy for PB. This band corresponds to the well-admitted emission usually attributed to the non-bridging oxygen hole centres in amorphous silica [4]. Our hypothesis concerning the TSL mechanism involving hole traps is somewhat comforted by the presence of these NBOHC centres known as a possible “reservoir” for released holes.

Another interesting feature on the data of Fig. 1 concerns the TSL intensity of the characteristic emission of Yb ions that is almost twice higher in the case of PB preform made from substrate tube of higher quality. It suggests that the emission efficiency of Yb is much better when this impurity is seen by the released holes during stimulation as the only possible recombining centre than when occur some competing centres (as for PA preform).
The TSL spectral analysis relative to the lower quality substrate-tube (TA) does not show any feature at around 1.9 eV and the substrate-tube TB is not thermoluminescent at all. So, one can consider that NBOHC centres may arise effectively from the presence of Yb doping or during collapse. This is in good agreement with results of Dragic et al. [5], which showed that the introduction of Yb species increases the NBOHC concentration.

5 CONCLUSION

We characterised the TSL properties of two identically Yb doped preforms after X- irradiation. Our data suggest that the TSL mechanism occurring in the preforms may be explained in terms of a redox process involving hole traps. The proposed mechanism is supported by the presence of NBOHC centres whose content seems to depend on the quality of the substrate tube used for the preform growth. Thus, to guard against possible problems of photodarkening in Yb doped fibres; it is shown here that the choice of the substrate-tube upstream might be a criterion that could be important on the quality of the preform.

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